Pest Management

A pilot project exemplifies new ways of dealing with important agricultural pests.

Ronald L. Giese, Robert M. Peart, Roger T. Huber

Agricultural pests can be successfully managed with less use of chemical pesticides than in the past. This has been shown by studies and pilot programs in pest management, which seek to restrict pest numbers to economically acceptable levels by combining natural factors with compatible chemical and cultural supportive measures rather than to destroy the maximum number of pests. An objective is to optimize the benefits compared to the costs of pest control, while reducing disruption and degradation of the environment (*1*).

The need for new approaches to managing pests has come about because (i) the idea that insecticides could control all insects has lost support (*2*), (ii) there is renewed interest in environmental quality (*3*), and (iii) it has been demonstrated that exclusively chemical methods can be replaced by alternative methods based on sound ecological principles (*4*). Agricultural scientists now realize that what they work with must be considered as an ecosystem (*5*) and that a greater understanding of that system is required for man to coexist successfully with pest species.

In an era when more food must be provided by methods that are economically competitive and environmentally compatible, pest management should be researched and applied more broadly. New production techniques are long overdue, and innovative methodology for managing crop pests is essential. In this article we discuss ideal pest management systems in general terms and then specifically outline a pilot program, the Purdue Alfalfa Pest Management Project, now in its third year in Indiana. This elementary program is based on crop ecosystem simulation, automated weather data acquisition, and a computer-based management information system.

Modern Pest Management Programs

Pest management involves the real-time synthesis of crop ecosystems through analysis of their behavior, and implementation of the appropriate control measures to maintain pest populations below a dynamic damage threshold; it is based on predictable ecologic, economic, and environmental outcomes and has the function of providing the fundamental information necessary for action decisions by the end user. Pest management is inclusive of former methods, integrating the best technology from biological, cultural, and chemical approaches. It is dynamic and regional, in that different techniques may be employed under different conditions. Thus it requires a continuous input of information about regional population patterns and environmental factors. It is predictive, utilizing systems methods to simulate and forecast biological and physical events, and quantitative, being based on numerical data and analysis. Finally, pest management is interdisciplinary in its approach during both development and implementation, to provide a broad knowledge base and create synergistic solutions. Forms of pest control have been used for thousands of years, but in the present sense of the term pest management is a new endeavor.

Despite the many benefits of this approach, pest management is not in widespread use for a variety of reasons (*6*). First, the number of techniques available is limited. Establishment of parasites or predators of the pest insects is occasionally beneficial. Cultural practices such as chopping plant stalks, burying crop residues by "clean" plowing, or harvesting the crop earlier have been used for cotton, corn, and alfalfa in some areas. Reduction of chemical spraying has aided the parasites of some fruit insect pests, but not others. The practice of releasing sterile males has controlled fruit flies, but only in selected habitats. Electrical and other traps have proved useful for monitoring populations, but not generally for control. Second, the farming community, which has relied heavily on pesticides for many years, is insecure about giving up a convenient system of cheap insurance, even though the chemicals may not always be necessary. Higher farm prices make the possible losses from insects even more important. Third, there appears to be an inadequate supply of trained professionals to guide growers in successful pest management. Finally, and of major importance, for many crops and pests there are large information gaps in crucial areas such as economic thresholds. The population of a pest that will produce significant losses varies with crop variety, cultural practices, weather, and especially with the developmental stage of the crop relative to that of the pest population. All these interactions must be evaluated in order to construct meaningful and reliable management models.

The digital computer and the development of systems analysis and simulation have made it possible to use quantitative approaches in evaluating pest populations (*7*) and crop-pest interactions. By use of these techniques it is possible to visualize crop ecosystem development quantitatively and on a day-by-day basis as frequently as pertinent weather data are available. In addition, the process of developing a dynamic simulation of crop and insect development quickly pinpoints areas of missing knowledge and provides a stimulating research challenge.

Financial support leading to pest population management projects began in 1972, and primarily came from two different sources. The U.S. International Biological Program (IBP), through the National Science Foundation, began support for fundamental research into the principles and strategies of pest regulation and control in major crop ecosystems, and the U.S. Department of Agriculture (USDA) made funds available for pest management programs oriented toward applications. A joint project initiated in 1972 by the Extension

Dr. Giese is director of the Natural Resources and Environmental Science Program and professor of entomology and Dr. Peart is professor of agricultural engineering at Purdue University, West Lafayette, Indiana 47907. Dr. Huber is associate professor in the Department of Entomology, University of Arizona, Tucson 85721.

Service and the Animal and Plant Health Inspection Service of the USDA is aimed at growers. The project, which covers work in 19 commodities and 29 states, provided $2,061,800 in fiscal year 1974 for 39 pilot pest management programs (*8*). The original programs were to be fully developed in 3 years, but experience has shown that more time is needed to bring the concept and the pilot projects to fruition. An approach of separate development, where one group works on basic research while the other is responsible principally for delivery, has been adopted by most projects; to succeed, their efforts must be integrated both conceptually and practically (*9*).

Alfalfa Pest Management

For many years most state Extension Service (*10*) offices have used printed publications to disseminate information about insect pests. However, such documents cannot generally account for wide differences in weather within state boundaries or for differences in the distribution and development of insect pests. With advancements in systems science and lower costs and improved capability in computer technology, the time has arrived when agriculturalists can exploit new and better methods of information analysis and transmission. Computers and remote terminals are being used to provide timely and easily accessible recommendations in a dynamic format by Extension personnel in several states (*11*).

The key concepts in the original Purdue plan developed in 1971 (*12*) were:

1) Effective crop production depends on management of the entire crop system including weeds, diseases, and insects, as well as on such factors as variety, fertility, seeding, and harvesting.

2) Daily weather data from the state Agricultural Weather Network should be the basis for rapid update of the crop and pest simulations throughout the state.

3) Research activities must be aimed at providing any missing knowledge of interactions needed to make the simulations realistic enough to be useful.

4) Modeling programs must be designed for practical use to ensure implementation.

5) The results of simulation runs and field sampling and the recommendations based on these results should be made available immediately to the grower, possibly by use of a computer terminal in the county Extension office.

In the Purdue program a model or a set of models are constructed on the basis of research data on the crop ecosystem. By using current weather data, the status of the crop ecosystem can be simulated in real time for various areas of the region, and recommendations for managing pests can be made. In addition to weather services, other information sources such as pest surveys, agricultural statistics, and archives yield important data. Finally, a supporting research program fills in gaps in our knowledge and generates simulation models. The objective of the program is to produce pest management advisories in several formats, aimed at the Extension agent, the individual grower, or groups of growers in a region; in the latter case the mass media might be involved. Figure 1 outlines the steps involved in a sequential way and shows what activities are required to meet the objectives, which steps can proceed simultaneously, and how the program can be segregated into logical working units.

At present, the business of pest control is conducted directly through the

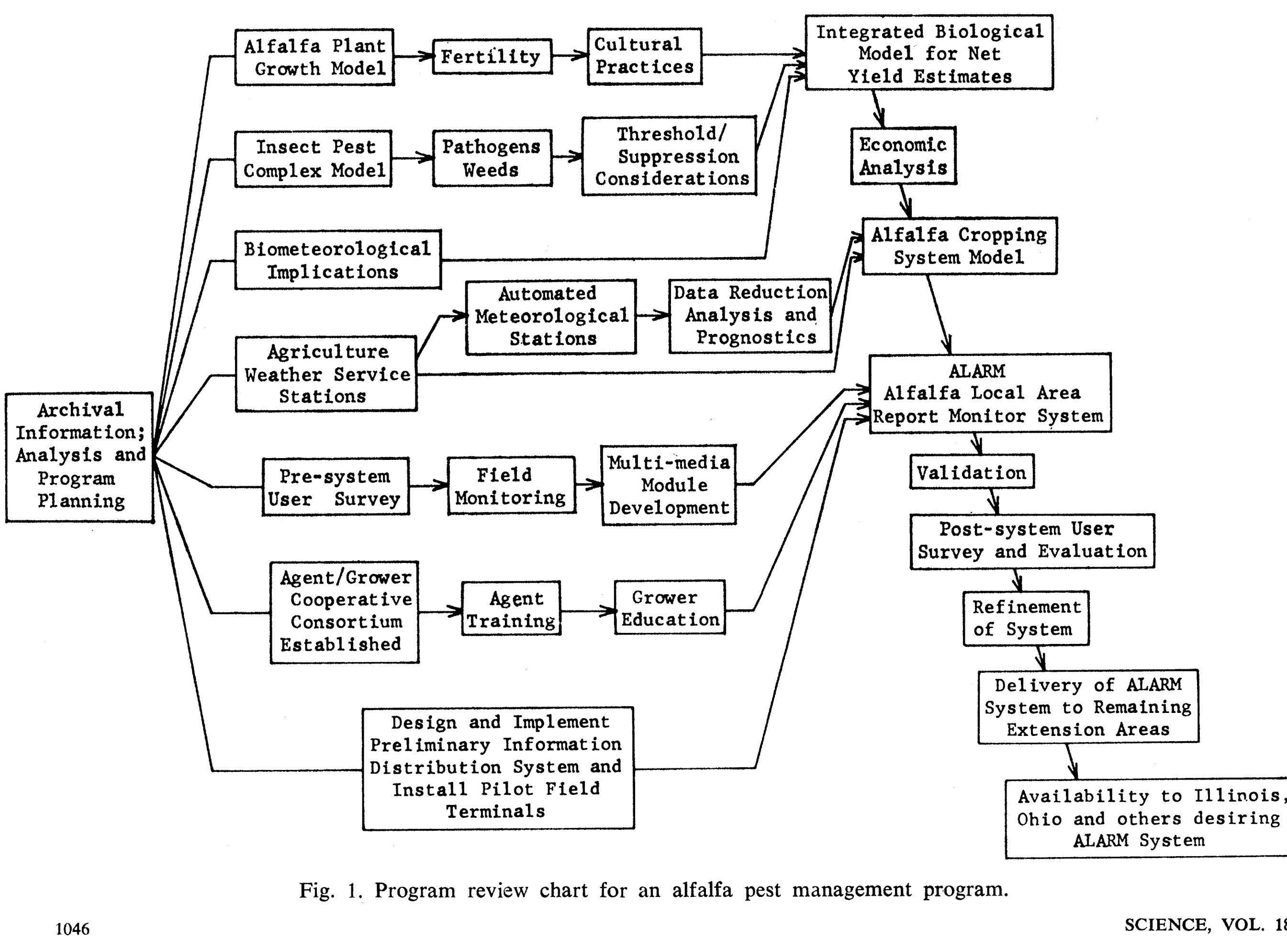
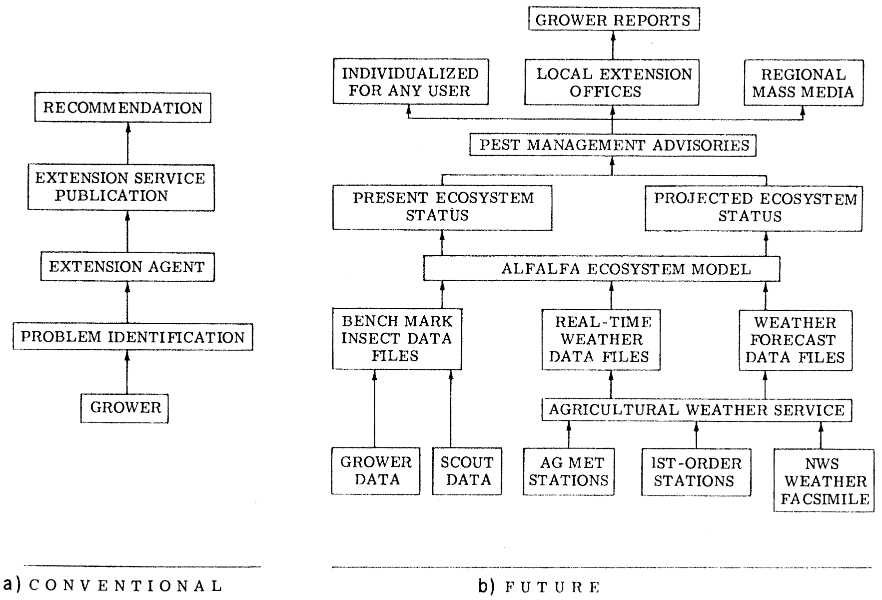


Fig. 1. Program review chart for an alfalfa pest management program.



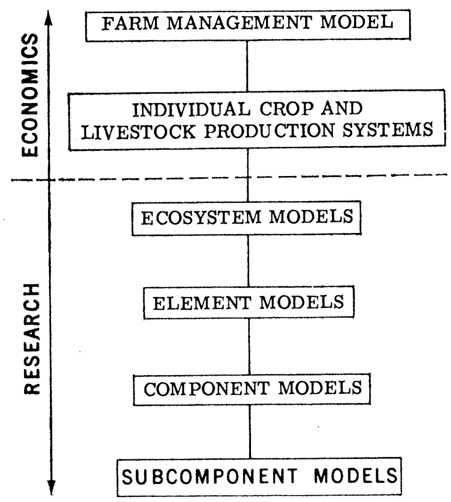


Fig. 2 (left). Generalized models of (a) the existing Extension process and (b) a proposed future process. Abbreviation: AG MET, agricultural meteorological. Fig. 3 (right). Hierarchical concept for modeling agricultural systems.

Extension agents. A generalized model of this process is shown in Fig. 2a. First, the grower identifies his problem and communicates with an agent. This specialist, after confirming the problem, usually consults a printed document and makes a recommendation. This is somewhat simplistic, but it does represent how Extension work is often done—and necessarily so, considering the tools at hand. We propose a more complex system, but one which has a high probability of improved service for a greater number of people. The flow chart shown in Fig. 2b represents the proposed future system. Not all parts of the plan are fully implemented yet, but we will explore the fragments now in use in the following sections.

Biotic Modeling

Many conceptual approaches to modeling are available; the classification scheme shown in Fig. 3 is based on Clymer's concept (*13*) of hierarchical modeling (*14*). Most experimental research is done at the level of elements and components; for example, an element could be a particular insect (such as the alfalfa weevil) and a component might be oviposition, flight, or another of the numerous primary activities. When we bring together two or more elements—for example, an insect and a plant—we approach modeling at the ecosystem level. If machinery, cultural systems, and other factors are integrated into ecosystem models, then whole crops can be considered. When two or more production areas are combined, the level attained is farm management. The two items above the dashed line in Fig. 3 tend to be considered part of economics and management, while the factors below the line usually represent biological and physical approaches. For an excellent discussion of systems methodology related to scientific research, the reader is referred to Witz (*15*).

For the alfalfa problem, two initial models were developed. The alfalfa plant can be represented by a mass flow model with environmentally and physiologically controlled rates of flow (Fig. 4). The model is based on physiological processes; usable equations have been devised for each phase, coding has been completed, and the algorithm is currently being validated in the field (*16*). The plant simulator (SIMED) produces output in terms of quantities of dry matter and carbohydrates; this is illustrated in Fig. 5, which is based on weather data from 1967, a year in which intensive plant data were also available. The top curve in Fig. 5, with slight diurnal variations, reflects the aboveground dry matter for a 5-day period. When the simulation results

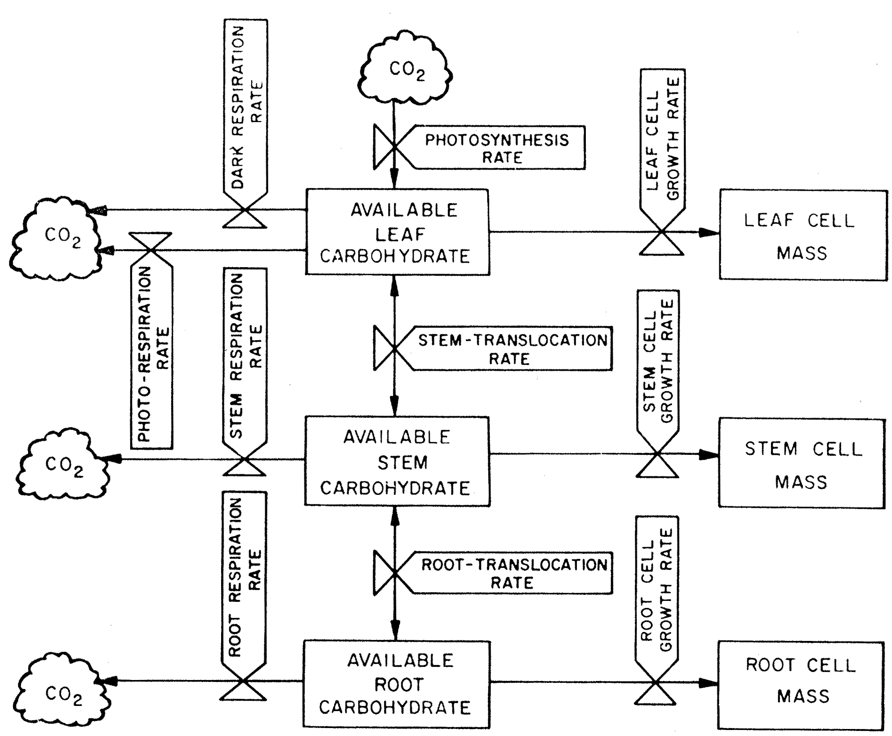
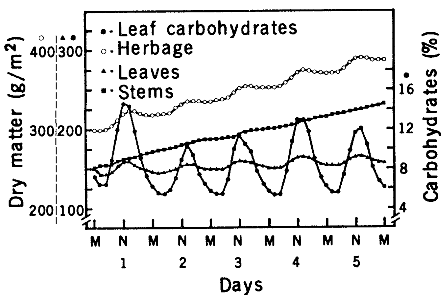
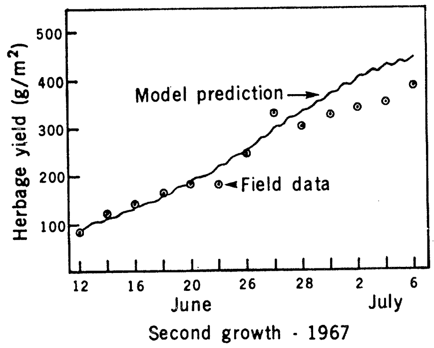


Fig. 4. Dynamic system model of the alfalfa plant.





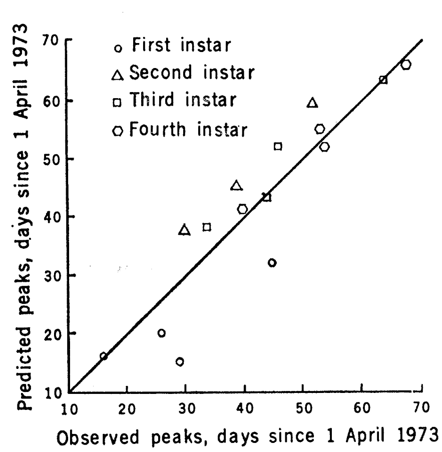


Fig. 5 (left). Simulation output using 1967 meteorological information. Abbreviations: M, midnight; N, noon. Fig. 6 (middle). Predicted dry matter accumulation for second growth (1967) alfalfa compared to observed accumulation at the Purdue University agronomy farm. Fig. 7 (right). Predicted instars of the alfalfa weevil compared to observations from four counties in Indiana. The line shows where observations equal predictions.

were compared to the measured second growth of dry matter in that year, it was apparent that the simulator overpredicted growth late during the growth period (Fig. 6). Still, the simulated second and third growths compared favorably, in general, with the measured growths; although there were differences in initial growth rates, the final yields of the simulation model were nearly identical to those measured. These results represent the first approximation, and the model is being refined. One important result of the early use of the model was the indication that soil moisture should be included as a variable to improve precision. Generally, the systems approach should provide guidelines of this kind —hints at information gaps that do not always seem obvious to the investigator.

Similarly, a model is available for the alfalfa weevil, and coding has been completed for this system, which is primarily a function of temperature (*17*). In its initial stage of development, the insect model produced output (Fig. 7) of variable reliability. The time of appearance of the insect's first instar was not predicted well by the simulator, but this stage is difficult to distinguish from the second instar in the field. The second instar is somewhat more realistically predicted by the program. For the appearance of the third instar the expectation is even more accurate, and the fourth (final larval) stadium is predicted to within 1 day, on the average. What this means is that we can forecast, within reasonable tolerances, when the alfalfa weevil will reach population peaks during its various life stages, by using just weather and initial conditions as inputs to the model. Ultimately, a model to express the alfalfa ecosystem is required. As a first step in establishing a simulator for the whole crop, the two separate algorithms for the alfalfa weevil and the alfalfa plant are being integrated into a single model.

Real-Time Forecasting

The geographic area covered in the Purdue program includes 16 counties in the primary alfalfa growing regions in Indiana (Fig. 8). The use of the models in the forecasting system has been described above; the sources of input to the system (Fig. 2) are related to the insects and weather. All insect data are provided by scouts, who regularly monitor the fields of cooperating growers. The status of the pest (and of the host plant) is assessed in terms of heat units, which are daily temperature accumulations above a defined threshold. Weather data are placed on files in a computing system and used in two ways: (i) daily entries are made in the real-time file to update heat units, and (ii) weather forecasts, generated locally, are stored for transmission over the terminals.

As an example of the first use of weather data, Fig. 9 shows the heat units accumulated above threshold temperatures important for adult activity, egg development, and larval and pupal development, for several stations on 31 March 1974. This kind of information not only allows the modeled system to be brought up to date with each new entry, but also serves as an early warning system to initiate field sampling of insect pests. On the basis of this knowledge, we have revised our original sampling procedure of fixed weekly sampling. When heat units are sequentially accumulated for specific areas, progress of both plants and insects can be anticipated. Unseasonably warm temperatures in February and March at one location advanced the heat unit curve strongly upward (Fig. 10). Comparison of this curve with a calculated normal curve based on records for 29 years (Fig. 10a) showed that the injurious stages of the alfalfa weevil would occur 3 to 4 weeks earlier than might have been expected.

Heat unit accumulation curves can be combined with forecasts not only to chart the progress of field phenomena, but also to anticipate critical events. For example, two separate forecasts are shown in Fig. 11; in practice, forecasts are updated daily to take advantage of new information.

The final step in this pilot pest management system is to produce advisories (Fig. 2) and make them available to growers. Currently, the advisories are made available through local Extension personnel to conform to established protocol. At this stage of development, the advisories result from both conventional sources and computer forecasts. As advisories are written, they are entered into a file to which access is available through terminals at locations away from the central campus. A recent advisory, shown in Fig. 12, exemplifies the kind of information made available. In addition to insect pest advisories, there are separate files on disk for fertilizers, weeds, chemicals, and weather for the major alfalfa growing areas.

Weather Data and Computational Needs

For real-time forecasting of insect pests it is necessary to have up-to-date meteorological information. Not all scientists involved in pest management planning and operation realize how much the lack of current data can affect the utility of models. Among those who recognize its significance are Haynes *et al.* (*18*), who stated, "One of the principal factors limiting usefulness of predictive models in any pest management program is ability of scientists to obtain real-time information." They proposed a basic scheme for monitoring biotic and abiotic factors that includes dedicated monitoring stations. The system they envisioned involves "remote-site data-acquisition stations [which] must be capable of reporting . . . on essentially a real-time basis so that near-term pest-management decisions can be made and farmers alerted." In their proposed system, environmental data would be sent through a communication channel to a central location for processing, storing, and dissemination to agricultural biologists, who would use it in formulating management decisions to be communicated to farmers as recommended pest control strategies. A prototype of such a monitoring system is already in place as part of the Purdue program.

The Agricultural Weather Service in Indiana, which is sponsored jointly by the National Weather Service (National Oceanic and Atmospheric Administration) and the USDA Agricultural Experiment Station, has 21 monitoring stations throughout the state. Normally these stations furnish data manually by telephone once a day. Six of the stations are or will be automated completely and will be used for many activities, including pest management. The approach we are using to automate the stations is to incorporate a microcomputer for monitoring, storing, integrating, and transmitting information on meteorological variables. The prototype microcomputer was constructed, tested, and operated in 1973. Early in 1974 two more units were installed, and construction of several more is in progress. As it is programmed, each weather microcomputer samples each of 16 sensors 240 times per hour, integrates or averages over each hour, and stores 29 hourly values for each sensor. Memory of the microcomputer weather stations is interrogated as often as necessary by a centrally located minicomputer, but no less than once each day. The information available includes data on solar, net, and infrared radiation which are not available from first order stations of the National Weather Service.

Now, instead of a once-daily provision of data from weather stations, we have the capability of automatic interrogation by a centralized computer. Just as it was impossible to seriously consider insect forecasting without including weather, it is equally hard to envision an operable pest management system without computer support. The Purdue project is possible largely because of the presence of a specialized computing facility, MIRACLE (*19*), which was designed to utilize a dual processor approach to collect and analyze laboratory and field data in a real-time on-line mode. The parts of the computing center facilities that are important to the Purdue project are depicted in Fig. 13. MIRACLE is a hierarchical computing network which, rather than relying on one large batch-oriented computer, has computers of various sizes and different capabilities joined in a network to make the most effective use of each machine. At the bottom of the hierarchy are the microcomputers already mentioned. Access to them is through the data acquisition processor. A main processor unit controls the operations of the rest of the network and is also used in analysis of data. The main processor also houses the Alfalfa Local Area Report Monitoring system used in the pest management program for handling advisories (*20*). Telephone communications with outlying terminals also go through the main processor. The MIRACLE center is hard-wired to a macrocomputer which

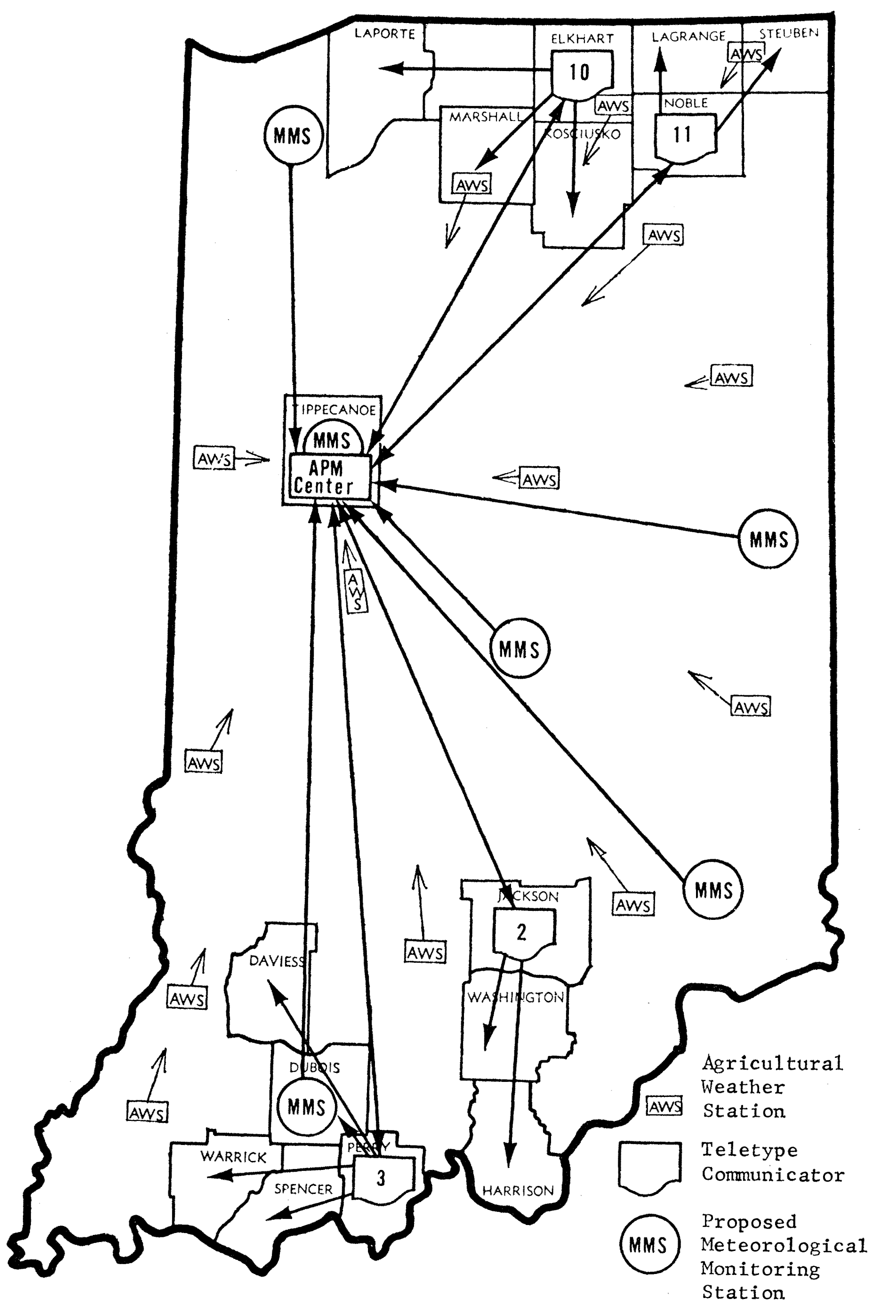


Fig. 8. Areas served by the pilot alfalfa pest management (APM) program and specialized meteorological information sites available.

serves the entire university and which is used (i) for simulations demanding large storage capacity and high speed and (ii) as a backup communications link should telephone or computers fail at the MIRACLE computing site.

Advantages of a Real-Time System

Under ideal conditions of development and implementation, real-time pest management schemes have several advantages over conventional systems.

1) They are dynamic, changing as a function of weather, population trend, crop variety, soil type, fertility level, or cultural practice.

2) They allow advanced planning for the particular circumstances of each

HEAT UNIT ACCUMULATION SUMMARY
31 MAR 1974

STATION NAME	HEAT UNITS 33	44	48	49
TERRE HAUTE	722	273	185	170
SOUTH BEND	438	113	75	68
FORT WAYNE	377	90	54	50
INDIANAPOLIS	729	279	185	170
EVANSVILLE	1076	483	338	309
LOUISVILLE	1083	478	324	296
CINCINNATI	811	313	199	174
CHICAGO	352	71	42	39
LAFAYETTE	568	199	132	118

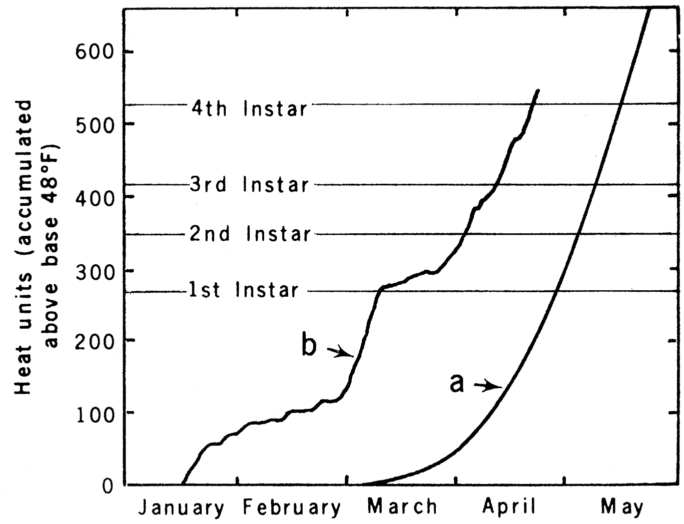


Fig. 9 (left). Heat units accumulated above threshold temperatures for adult activity (33°F), egg development (44°F), larval development (48°F), and pupal development (49°F) of the alfalfa weevil. For example, adults are active at temperatures above 33°F; when 3300 heat units have accumulated above this temperature, all eggs have been deposited. At the stations shown in this computer output table, adult females were still laying eggs on 31 March 1974. Hatching, larval development, and pupal development are complete when 313, 298, and 215 heat units have accumulated above the respective threshold temperatures. When each of the sums required is satisfied, adults emerge. Fig. 10 (right). (a) Calculated normal heat unit curve based on records for 29 years. (b) Actual accumulation record for 1974. By comparing the observed and calculated curves it was predicted that the injurious stages of the alfalfa weevil would appear 3 to 4 weeks earlier than expected.

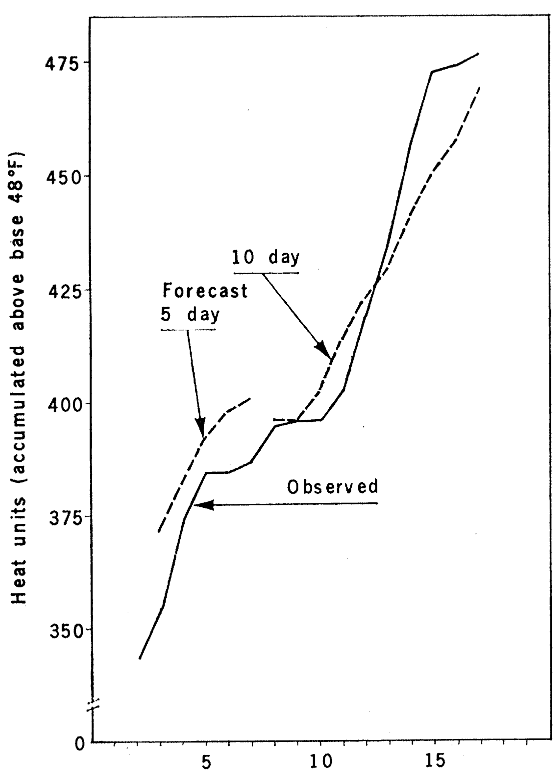


Fig. 11 (left). Observed and forecast heat unit accumulation for Louisville, Kentucky. Fig. 12 (right). Alfalfa pest management advisory at a remote terminal.

INSECT CONDITIONS -- SOUTH MARCH 28 , 1974

300 HU(HEAT UNITS) ADVISORY

ALFALFA WEEVIL LARVAL POPULATIONS ARE ON THE INCREASE AND HAVE REACHED SUFFICIENT LEVELS IN MANY COOPERATORS' FIELDS IN SOUTHERN INDIANA TO EVENTUALLY RESULT IN ECONOMIC LOSSES. THE ALFALFA IN THESE

FIELDS IS STILL RELATIVLEY SHORT, AVERAGING 4.6 INCHES AND ***SHOULD NOT*** BE TREATED AT THIS TIME..

LARVAE IN ALL FIELDS ARE STILL HATCHING , THUS , FOR THOSE FIELDS WITH HIGH POPULATIONS AT 300 HU , INSECTICIDE APPLICATION SHOULD BE DELAYED UNTIL MORE LARVAE HAVE HATCHED SO THAT A GREATER NUMBER CAN BE CONTROLLED. DELAY INSECTICIDE APPLICATION FOR 7 TO 10 DAYS FROM THIS ADVISORY , MARCH 28.

THE FOLLOWING GROWERS HAVE SUFFICIENT LARVAL NUMBERS AND SHOULLD SPRAY ACCORDING TO THE TIME TABLE ABOVE.

DAVIESS COUNTY - GRABER,HAWKINS,MCKEE,SCHUETZ
WARRICK COUNTY - BECKLEY,MOESNER
DUBOIS COUNTY - BEGLE,DILGER
SPENCER COUNTY - LEUKEN,ST. MEINRAD
ORANGE COUNTY - M. JONES
HARRISON COUNTY - J. DAVIS,B. DAVIS,BOLDT
WASHINGTON COUNTY - WATHEN,PONSFORD,NICHOLSON
JACKSON COUNTY - STAHL,SCHEPMAN

ALL COOPERATORS SHOULD CHECK ALFALFA NOT INCLUDED IN THE PEST MANAGEMENT

PROGRAM FOR ALFALFA WEEVIL LARVAE. IF AT LEAST 25 STEMS OUT OF 100 STEMS (25%) HAVE SMALL PIN-HOLE FEEDING DAMAGE IN THE TIPS AND SMALL WHITISH-GREEN "WORMS" CAN BE SEEN, IT WILL PAY TO TREAT IN 7 TO 10 DAYS FROM THE 300 HU ADVISORY , MARCH 28 . IF SOME FIELDS DO NOT HAVE 25% OF THE STEMS SHOWING DAMAGE AT THIS TIME, DO NOT SPRAY.

WAIT FOR INSTRUCTIONS IN THE 400 HU ADVISORY.

IF LOW TEMPERATURES, BELOW 60 DEGREES F , ARE PRESENT WHEN SPRAYING IS NECESSARY DO NOT TREAT INFESTED FIELDS WITH MALATHION OR MALATHION COMBINATIONS.

REFER TO THE INSECTICIDE RECOMMENDATON FILE FOR RECOMMENDATED MATERIALS.

WHEN CHOOSING AN INSECTICIDE ***NOTE*** THE HARVEST OR PASTURE RESTRICTIONS.

season with the use of regular monitoring and simulation activities.

3) With a better understanding of biological processes and the capability for improved forecasting, we should be able to anticipate where and when problems will occur.

4) For similar units of information the cost should be less; it is possible, however, that when more information is desired the absolute cost could be greater.

5) They can be used by all growers, whereas only a limited number can be handled on the basis of individual inquiry; in addition, the proposed system would be accessible to commercial management concerns, farm products outlets, and mass media.

6) Properly implemented, they should always be up to date.

7) They should be more reliable than conventional systems because simulations can account for variations and interactions.

8) Unless Extension personnel have almost continuously followed developments in specific fields they must assume the "worst case" in response to random inquiries. With acceptable models we can, through simulation, provide growers with a set of alternatives relating the likely consequences of different actions to yield, market values, weather outlooks, and so forth.

9) Normally, the Extension Service is expected to provide all the solutions; in a real-time system, with alternative strategies to consider, there are strong incentives for the grower to make his own decisions. Further, models should be designed to allow for the feedback of biological information by the growers, so that they can improve the accuracy of the advisory.

This comparison is not intended to question Extension Service operations; it simply says that we can do an even better job and that real-time approaches can be of tremendous assistance to Extension specialists. The incentives for changing are strong. Technology in systems science and computers has advanced greatly in the past decade and offers the capability of a better and more timely information base. Second, the demands on the Extension Service are increasing out of proportion to the available personnel. Third, some of what happens in nature is counterintuitive, and occasionally when we deal with highly interactive systems our judgment and intuition lead us to the wrong conclusions. Finally, it is not humanly possible to integrate all the important variables attendant in a complex system over as broad a geographic range as most Extension specialists deal with.

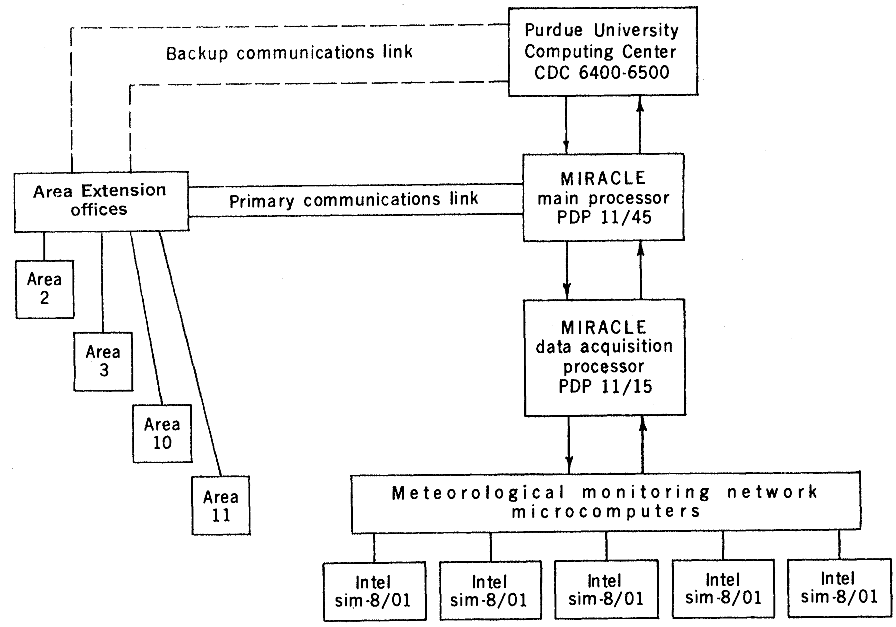


Fig. 13. Computing network used for acquisition, analysis, simulation, and transmission of pest management information.

Summary

Although it has not yet been universally adopted, pest management figures prominently in current planning. For pest management to be effective, agricultural scientists must adopt an interdisciplinary approach to solving problems; this means considering not only complexes of pests including insects, pathogens, and weeds, but whole crop systems. The requisites for successful pest management programs include availability of current weather data, cooperation between research and Extension personnel, and feedback from individual growers.

A pilot program for alfalfa pest control is in its third year of development at Purdue University. It involves the cooperation of entomologists, engineers, physiologists, economists, and agronomists, and research and implementation proceed simultaneously. Microcomputers are used for monitoring, integrating, storing, and transmitting meteorological information to a central location, where it is used in simulations of the alfalfa plant and the alfalfa weevil. The resulting advisories are produced at teletype terminals at four locations in the alfalfa growing region of Indiana. Our experience with this prototype system indicates that computer-based pest management programs will be dynamic and reliable systems capable of delivering alternative action strategies with virtually unlimited accessibility.

References and Notes

1. R. L. Rabb and F. E. Guthrie, Eds., *Concepts of Pest Management* (North Carolina State University, Raleigh, 1970).
2. "Insect-pest management and control," *Natl. Acad. Sci. Natl. Res. Counc. Publ. 1695* (1969).
3. *Goals for Science and Education in the U.S. Department of Agriculture* (Department of Agriculture, Washington, D.C., 1969).
4. P. W. Bergman and D. P. Sanders, Eds., *Implementing Practical Pest Management Strategies* (Indiana Cooperative Extension Service, Purdue University, West Lafayette, 1972).
5. G. L. McNew, in *Pest Control Strategies for the Future* (National Academy of Sciences, Washington, D.C., 1972), p. 119.
6. Council for Environmental Quality, *Integrated Pest Management* (Government Printing Office, Washington, D.C., 1972).
7. O. J. Loewer, Jr., R. T. Huber, J. R. Barrett, Jr., R. M. Peart, *Simulation* **22**, 113 (1974).
8. J. M. Good, *Pilot Pest Management Projects* [No. ANR-5-33(3-74), Extension Service, Department of Agriculture, Washington, D.C., 1974].

9. There is a serious danger that basic research in modeling insect pests might reach its end point as a set of monographs rather than in action programs. It is necessary to have a continuous dialogue between groups of researchers and Extension specialists to assure understanding of the systems and ultimate utility of the models. One common problem in pest management research is that modeling is often based on historic data (for both weather and insects) and it is suggested that the completed models be used with published weather information; the usefulness of such a system is, of course, limited because of the turnaround time for publishing standard weather data.
10. The USDA Extension Service, the states through the land-grant universities, and the counties comprise the Cooperative Extension Service, which provides information on agricultural subjects.
11. In its agricultural education effort, the Extension Service, through its state personnel, uses over 400 computer programs. The majority of usage is in farm management, primarily in financial and tax operations and

least cost ration problems. Information about kinds of programs available and their use is detailed in B. F. Lanpher, Ed., *Inventory of EDP programs used in Agricultural Extension* (Extension Service, Department of Agriculture, Washington, D.C., 1973). Initial efforts in use of computers for real-time forecasting are described in R. T. Huber and R. L. Giese, *Proc. North Cent. Branch Entomol. Soc. Am.* **28**, 139 (1973).
12. We presented these concepts in verbal and written form as a part of a cropping system proposal to officials of the USDA in September 1971. Represented were the Extension Service, Cooperative States Research Service, Animal and Plant Health Inspection Service, and Agricultural Research Service.
13. A. B. Clymer, *Simulation* **15**, 50 (1970).
14. G. E. Miles, *Purdue Univ. Agric. Exp. Sta. Bull. No. 50* (1974).
15. J. A. Witz, *Agric. Sci. Rev. Coop. State Res. Serv. U.S. Dep. Agric.* **11**, 37 (1973).
16. For a more complete description of the plant simulation, see G. E. Miles, R. J. Bula, D. A. Holt, M. M. Schreiber, R. M. Peart, *ASAE (Am. Soc. Agric. Eng.) Pap. No. 73-4547* (1973).
17. G. E. Miles, T. R. Hintz, A. B. Pritsker, M. C. Wilson, R. M. Peart, in *Proceedings of the 5th Annual Pittsburgh Conference on Modeling and Simulation* (University of Pittsburgh, Pittsburgh, Pa., 1974), pp. 1157–1161; G. E. Miles, R. M. Peart, R. J. Bula, M. C. Wilson, T. R. Hintz, *ASAE (Am. Soc. Agric. Eng.) Pap. No. 74-4022* (1974).
18. D. L. Haynes, R. K. Brandenburg, P. D. Fisher, *Environ. Entomol.* **2**, 889 (1973).
19. The acronym MIRACLE stands for multidisciplinary integrated research activities in complex laboratory environments. This is discussed in greater detail in R. B. Harrington and R. L. Giese, *Proc. Fed. Exp. Biol.* **33** (No. 12), 2393 (1975); D. C. Beckwith, *Am. Lab. (Greens Farms, Conn.)* **5**, 77 (1973).
20. R. M. Peart, R. T. Huber, W. H. Blake, D. R. Wolf, G. E. Miles, *ASAE (Am. Soc. Agric. Eng.) Pap. No. 74-5043* (1974).
21. We express appreciation for principal contributions in this integrated team effort to R. J. Bula (plant physiology), C. R. Edwards (Entomology Extension), R. B. Harrington (MIRACLE Computing Center), T. R. Hintz (insect impact), D. A. Holt (plant physiology), G. E. Miles (systems analysis), and M. C. Wilson (insect population dynamics). The Purdue Alfalfa Pest Management project is sponsored by the Purdue Agricultural Experiment Station, the USDA Agricultural Research Service (Agreement No. 12-14-3001-218), and the USDA Animal and Plant Health Inspection Service and Extension Service (Agreement No. 12-16-100-150). This article is approved for publication by the director of the Purdue Agricultural Experiment Station as Journal Paper No. 5627.

Limits to the Scientific Understanding of Man

Human sciences face an impasse since their central concept of the self is transcendental.

Gunther S. Stent

For the past two centuries scientists, particularly in English-speaking countries, have generally viewed their attempt to understand the world from the epistemological viewpoint of positivism. All the while, positivism had been under attack from philosophers, but it is only since the 1950's that its powerful hold on the students of nature finally seems to be on the wane. There is as yet no generally accepted designation for the philosophical alternatives that are replacing positivism, but the view of man known as "structuralism," which has informed certain schools in the human sciences, appears to be central to the latter-day epistemological scene (*1*). As I shall try to show in this article, in addition to the philosophical and psychological arguments that have been advanced in its behalf, structuralism can draw support also from biological insights into the evolutionary origins and manner of function of the brain. But whereas the work of structuralist scientists has shown up the essential barrenness of the positivist approach to human behavior, even the structuralist program, however meritorious, is unlikely to lead to a scientifically validated understanding of man.

The author is Professor of Molecular Biology at the University of California, Berkeley 94720. This article is adapted from a lecture given at a seminar on Mobility under the joint auspices of the American Foundation for the Blind and St. Dunstan's Society, held at Trinity College, Cambridge in September 1973.

Positivism

The principal tenet of positivism, as formulated in the 18th century mainly by David Hume and the French Encyclopaedists, is that, since experience is the sole source of knowledge, the methods of empirical science are the only means by which the world can be understood (*2*). According to this view, the mind at birth is a clean slate on which there is gradually sketched a representation of reality built on cumulative experience. This representation is orderly, or structured, because, thanks to the principle of inductive reasoning, we can recognize regular features of our experience and infer causal connections between events that habitually occur together. The possibility of innate or a priori knowledge of the world, a central feature of the 17th-century rationalism of René Descartes, is rejected as a logical absurdity.

It is unlikely that the widespread acceptance of positivism had a significant effect on the development of the physical sciences, since physicists have little need to look to philosophers for justification of their research objectives or working methods. Moreover, once a physicist has managed to find an explanation for some phenomenon, he can be reasonably confident of the empirical test of its validity. For instance, the positivist rejection of the atomic theory in the late 19th century, on the grounds that no one had ever "seen" an atom, did not stop chemists and physicists from then laying the groundwork for our present understanding of microscopic matter. However, in the human sciences, particularly in psychology and sociology, the situation was quite different. Here positivism was to have a most profound effect. One reason for this is that practitioners of the human sciences are much more dependent on philosophical support of their work than are physical scientists. In contrast to the clearly definable research aims of physical science, it is often impossible to state explicitly just what it really *is* about human behavior that one wants to explain. This in turn makes it quite difficult to set forth clearly the conditions under which any postulated causal nexus linking the observed facts could be verified. Nevertheless, positivism helped to bring the human sciences into being in the first place, by insisting that any eventual